SAND2002-0390P

Scaling RadJet Experiments to Z

JOWOG-37 — 2002

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Livermore, CA

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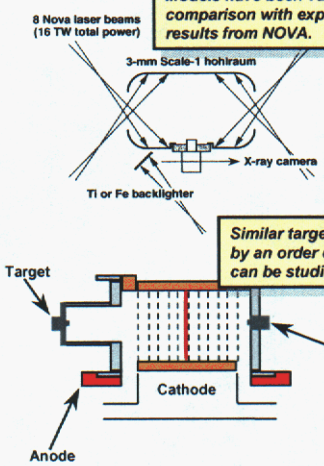
Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL85000.

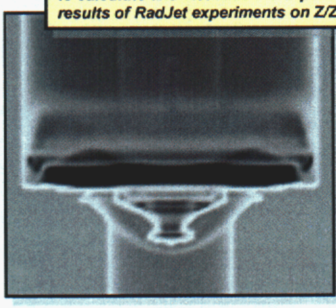
We are using the ASCI code ALEGRA to design radiation-driven jet experiments on Z.

Models have been validated by comparison with experimental results from NOVA.



Similar targets scaled up by an order of magnitude can be studied on Z.

ALEGRA and SPECT3D are being used to calculate and visualize the experimental results of RadJet experiments on Z/ZBL.



. . . the capabilities of Z and ZBL will allow scaled-up RadJet experiments applicable to Campaign 4.

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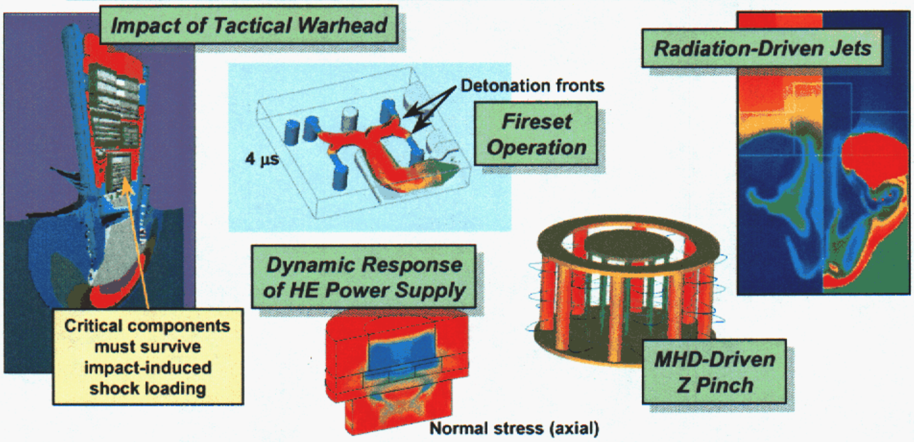
ALEGRA has unique capabilities for addressing SBSS program issues as well as HEDP problems.



. . . the code combines solid dynamics, fracture, HE, etc., with high-energy features such as MHD and radiation transport.

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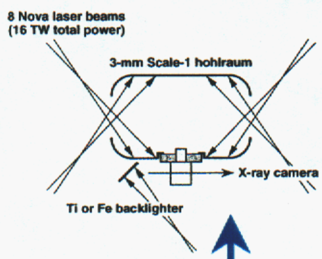
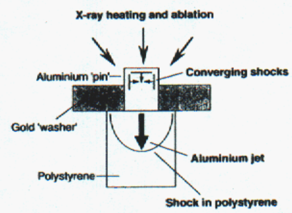
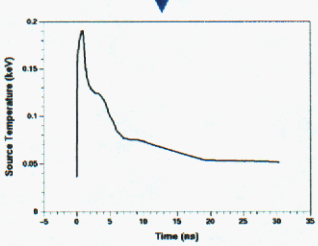
The NOVA experiments used radiation from a short-pulse, high-power, laser-driven hohlraum.



The radiation drive was a blackbody temperature history peaking at ~190 eV with a FWHM pulse width of ~5 ns.



The experiment used a laser-driven NOVA hohlraum to expose the sample to a short high-intensity radiation load. The sample response was observed with an x-ray backlighter.



The target configuration consisted of a 150-μm-long aluminum "pin" in a 50-μm-thick gold "washer," which was backed with a 380-μm-diameter polystyrene block.

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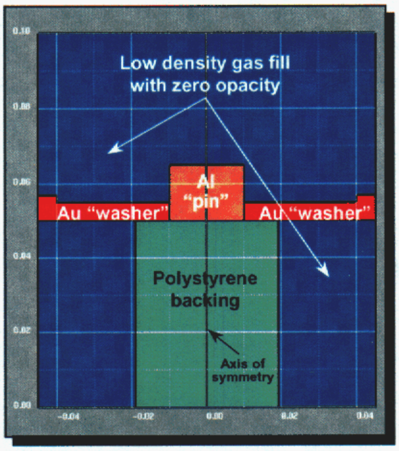
The basic configuration for the early ALEGRA calculations involved an Al "pin" in an Au "washer."

- *For the NOVA problem, the thickness of the aluminum "pin" was 150 μm, the gold washer thickness was 50 μm, and the polystyrene backing had a diameter of 380 μm.*
- *We used a 2-D cylindrical Eulerian mesh with: 1) 4,500 elements (10-μm resolution); and 2) 18,000 elements (5-μm resolution).*
- *The radiation, incident from the top, was treated with single-group, SN_1 radiation transport, with radiation pressure disabled.*



Dimensions in cm

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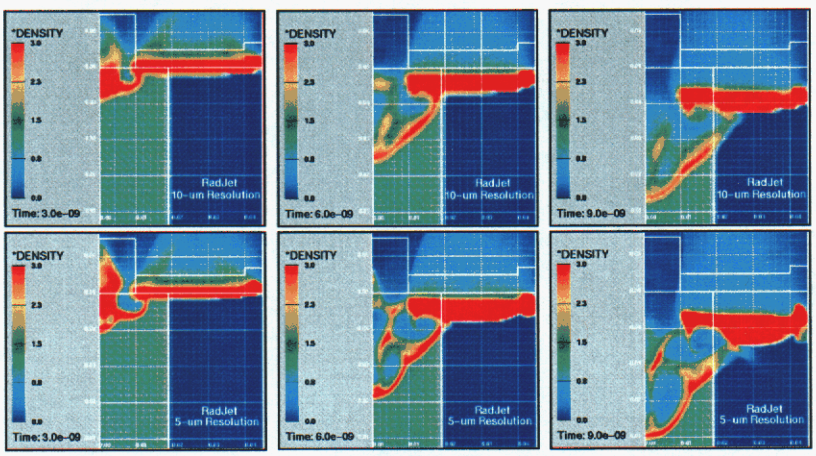
For NOVA, fine resolution calculations show more detail and slightly faster on-axis jet motion.

Coarse resolution calculation



Fine resolution calculation

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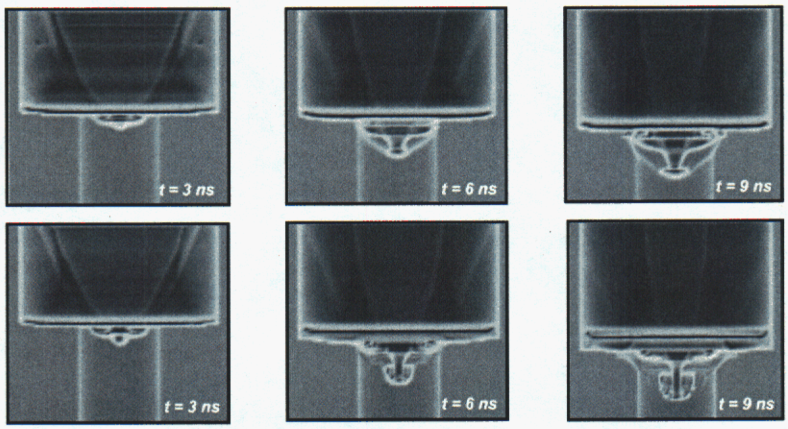
For NOVA, SPECT3D produces simulated radiographs from ALEGRA rad/hydro output.

Coarse resolution calculation →



Fine resolution calculation →

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The ALEGRA results for NOVA are consistent with other codes and with the experiment.

Spatial characterization of aluminum jet
(Revised configuration – coarse mesh):

[Axial position of leading edge (μm)]

Code	ALEGRA *(Eulerian)*	PETRA *(Eulerian)*	CALE *(ALE)*	RAGE *(AMR)*	Experiment *(Estimated)*
Time = 6 ns	265	245	300	280	~260
Time = 9 ns	380	345	405	380	300+
Time = 12 ns	460	–	–	–	–

- *At a computational time of 6 ns, ALEGRA predicts the on-axis jet location within about 2% of the estimated experimental result; this result is also consistent with the other computational efforts.*
- *At a time of 9 ns the predicted axial location of the jet is somewhat over 20% greater than the estimated experimental measurement; but as with the earlier time, it agrees very closely with the average of the other code results.*

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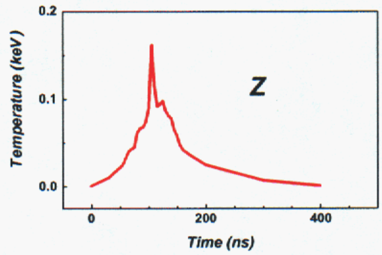
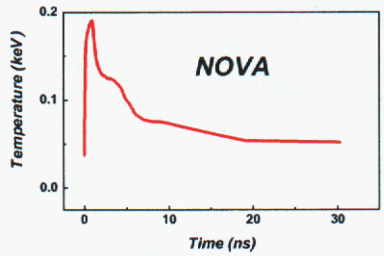
We have investigated the scaling of these RadJet experiments from NOVA to Z.





Typical Source Characteristics

Peak temperature:	
NOVA	~190 eV
Z	~162 eV
FWHM pulse width:	
NOVA	~5 ns
Z	~50 ns
Peak power:	
$P_{MAX}(Z)/P_{MAX}(NOVA) \approx 1/2$	
Total energy fluence:	
$\Phi_{TOT}(Z)/\Phi_{TOT}(NOVA) \approx 3$	

- ***Similar mechanical behavior should be obtained by scaling the physical dimensions by about a factor of ten.***
- ***However, the radiation transport will not scale in a similar fashion.***
- ***Source for Z can be modified.***

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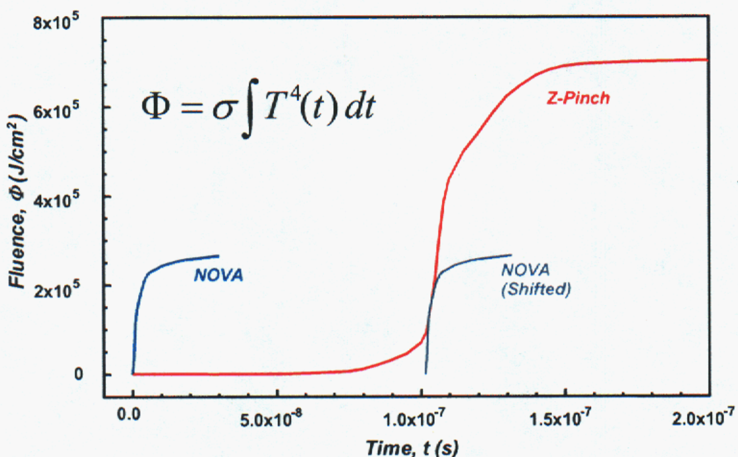
Integrating the temperature curves allows the energy fluences to be compared.



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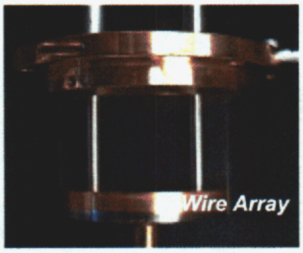
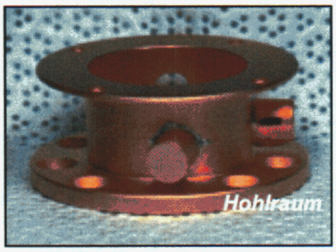
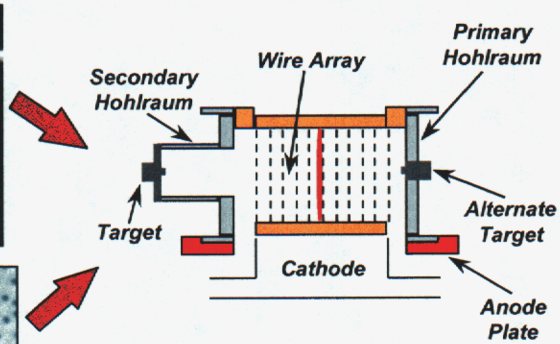
The Z experiments will use a longer pulse, but a higher total energy Z-pinch-driven hohlraum.







- *The target could be placed in either the primary or a secondary hohlraum.*
- *Principal diagnostics would involve the Z-Beamlet Backlighter (ZBL) that is now becoming operational.*

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There are several points that should be noted with regard to these RadJet calculations.

- The quoted half-max pulse widths are only approximate, but lead to about a factor of ten difference in characteristic response times.
- In these early calculations the physical dimensions are scaled by exactly a factor of ten for the two cases.
- Because the radiation transport phenomena (*e.g.*, opacities) do not scale in the same manner as the hydrodynamic behavior, the total response will not be directly homologous.
- The calculations were run with ALEGRA, using 10-µm resolution for the NOVA case and 100-µm resolution for the Z configuration.
- Because of the initial slow rise for the radiation drive from Z, the times cannot be shifted in a directly proportional fashion; the comparison plots were chosen for similar stages in the evolution of the response.

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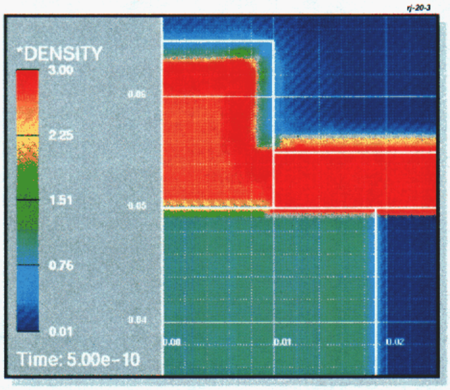
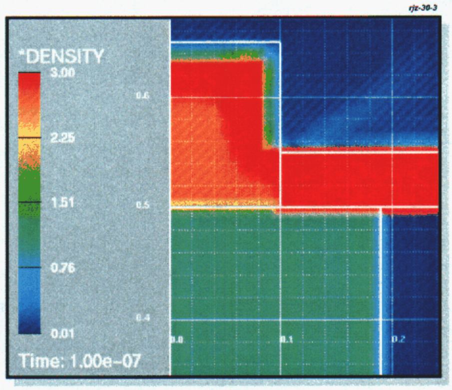
The RadJet problem at very early times, with the shock part way through the "pin" . . .

RadJet / NOVA:



10X Scale-Up RadJet / Z:



Dimensions in cm

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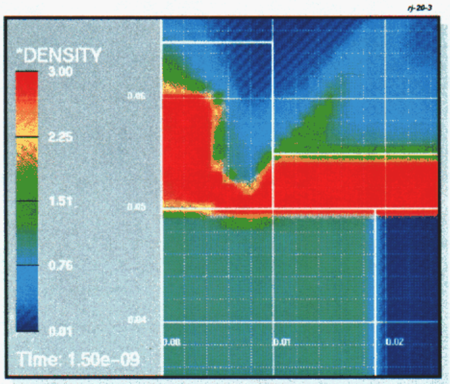
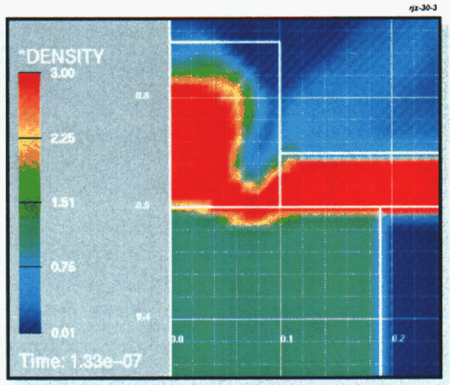
The RadJet problem at early times, at about the time of shock breakout . . .

RadJet / NOVA:



10X Scale-Up RadJet / Z:



Dimensions in cm

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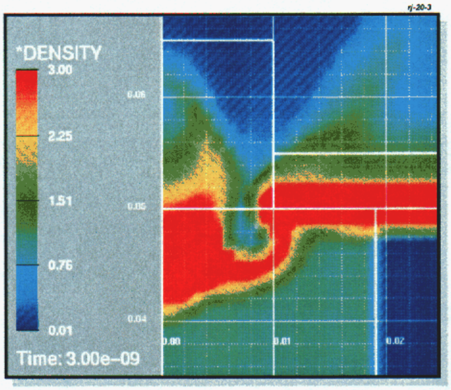
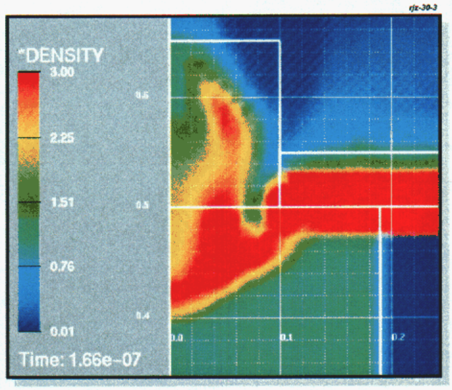
The RadJet problem at medium time, after the "jet" is relatively well formed . . .

RadJet / NOVA:



10X Scale-Up RadJet / Z:



Dimensions in cm

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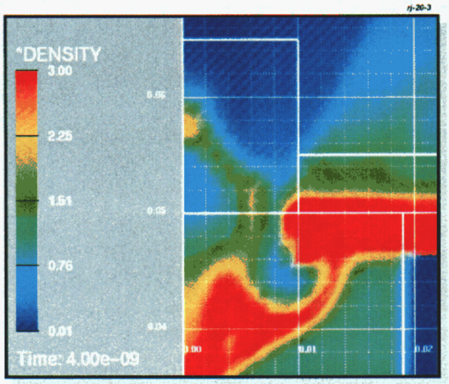
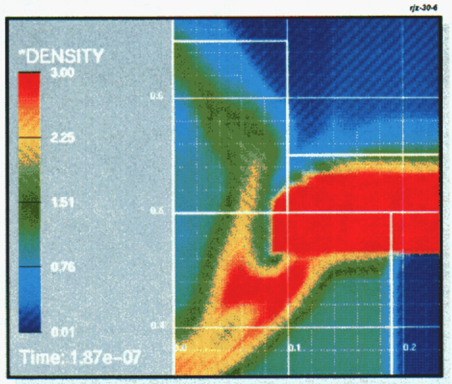
At later times the problems are still similar, and the jet is well into the polystyrene backing.

RadJet / NOVA:



10X Scale-Up RadJet / Z:



Dimensions in cm

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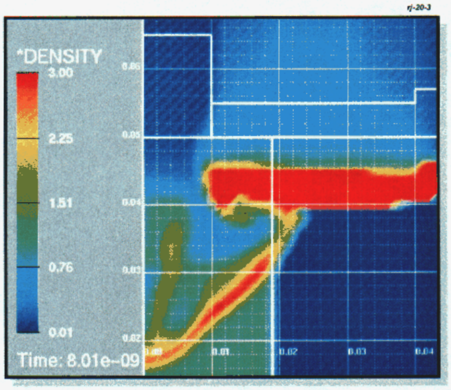
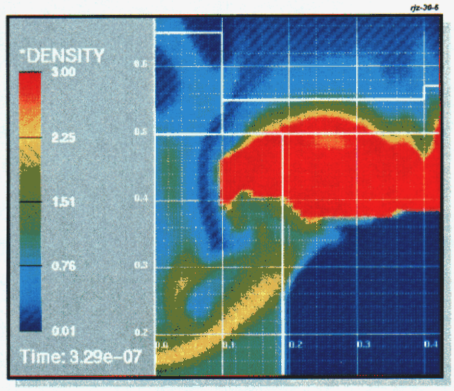
By late times, the differences due to lack of radiation "scaling" are considerably more evident.

RadJet / NOVA:



10X Scale-Up RadJet / Z:



Dimensions in cm

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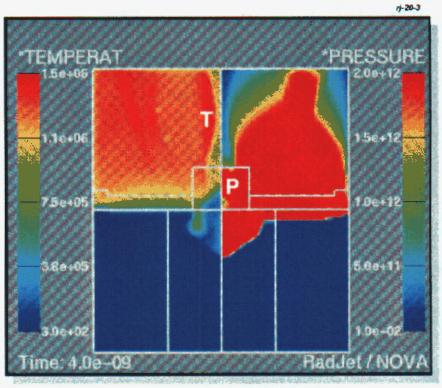
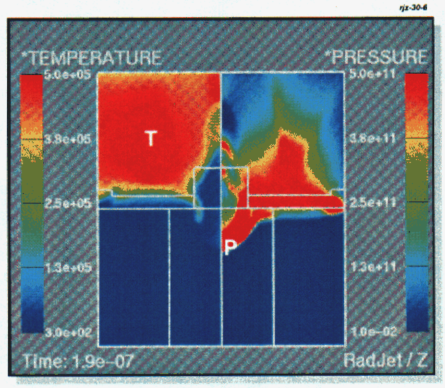
At moderate times temperatures and pressures show much larger differences than the densities.

RadJet / NOVA:



'T' – $T_{max} \cong 130$ eV
'P' – $P_{max} \cong 30$ Mb

10X Scale-Up RadJet / Z:



'T' – $T_{max} \cong 50$ eV
'P' – $P_{max} \cong 3$ Mb

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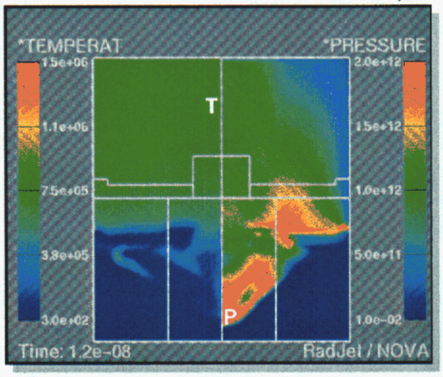
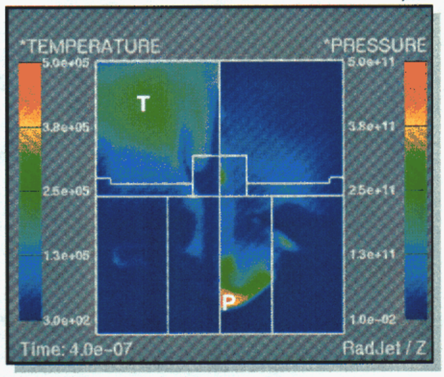
At much later times there are significant differences, but many qualitative features are similar.

RadJet / NOVA:



'T' – $T_{max} \cong 70$ eV
'P' – $P_{max} \cong 4$ Mb

10X Scale-Up RadJet / Z:



'T' – $T_{max} \cong 20$ eV
'P' – $P_{max} \cong 0.5$ Mb

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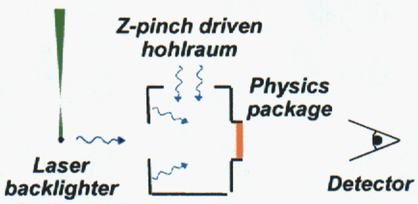
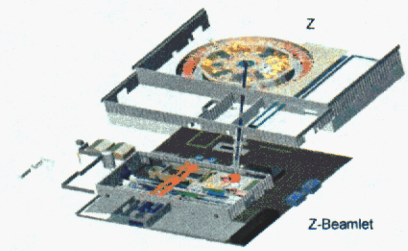
The ZBL is an important new diagnostic tool for high-energy physics experiments on Z.



2 TW laser backlighter on Z --



<u>Measurements possible with a backlighter:</u>

- **Material T_e and n_e**
- **Magnetic Rayleigh-Taylor growth rate**
- **Absorption spectrum**
- **Capsule implosion symmetry**
- **Material interface motion**
- **Particle velocity and shock density**
- **Instability mix region**

- **Capabilities include both point projection and area backlighting.**
- **We will have spatial resolution of 25 µm at 9 keV x-ray probe energy.**

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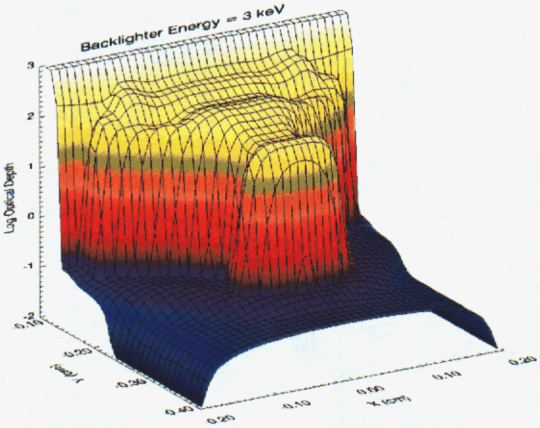
We are using SPECT3D to visualize data for the Z-Beamlet Backlighter (ZBL) on these experiments.

- ***The amplitude of each cell represents the optical depth through the jet as a function of axial position (Y) and offset from the axis (X).***
- ***Overall, ZBL performance depends on photon energy, conversion efficiency, and other issues.***
- ***This plot is taken from the 100-μm resolution 10X scale-up RadJet / Z calculation at a time of 330 ns.***
- ***For this example the backlighter energy was chosen as 3 keV, but the jet is probably too thick to "see" through – an optical depth approaching 100.***



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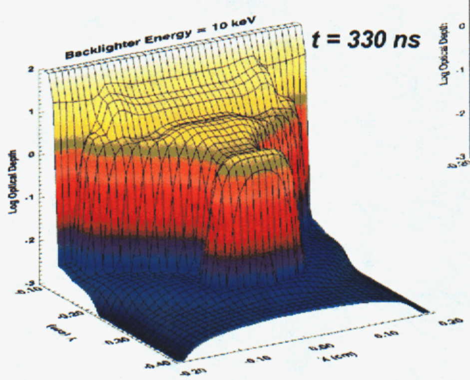
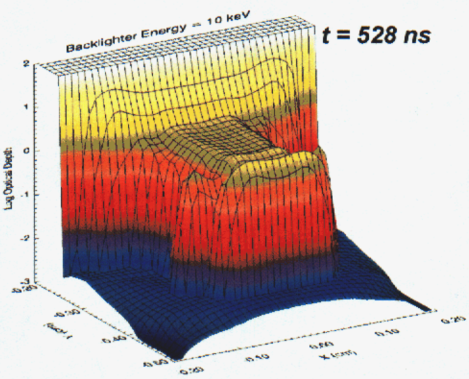
At late times and 10 keV, we get optical depths of order unity, which implies experiment is feasible.

Backlighter photon energy:
hν = 10 keV





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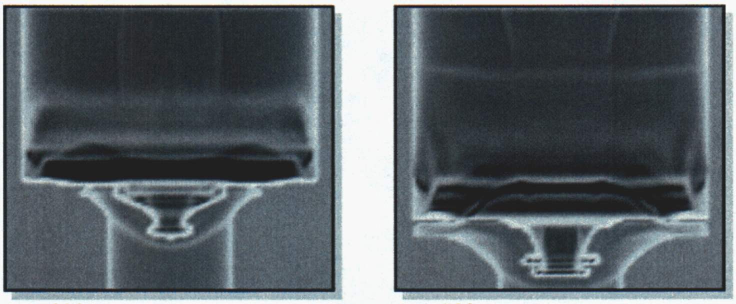
Simulations of detector output from the 10X scaled-up Z runs show all major features.

- *These images were generated with hν = 10 keV.*
- *Features evident in the radiographs include the polystyrene backing block, the shock wave in the polystyrene, and details of the aluminum jet in the plastic.*
- *Details of the blowoff moving back into the hohlraum are also evident, but would not be recorded in the experimental radiograph.*



t = 330 ns *t = 528 ns*

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For practical considerations, we decided to use a 5X scale-up of the physical configuration.

- We have employed an improved description of the vacuum hohlraum temperature history for Z.
- The initial ALEGRA calculations employed 30,000 elements and provided a spatial resolution of 20 µm.
- We removed the low-density gas fill used in the earlier calculations, and treat the relevant regions as vacuum.
- We wanted to consider the use of a 6.7 keV ZBL source.
- The problem ran to ~80 ns and then terminated due to a time-step anomaly –
  - This is 20 ns past the peak of the radiation drive;
  - Front-surface blow-off is well established, but jetting has not yet developed.

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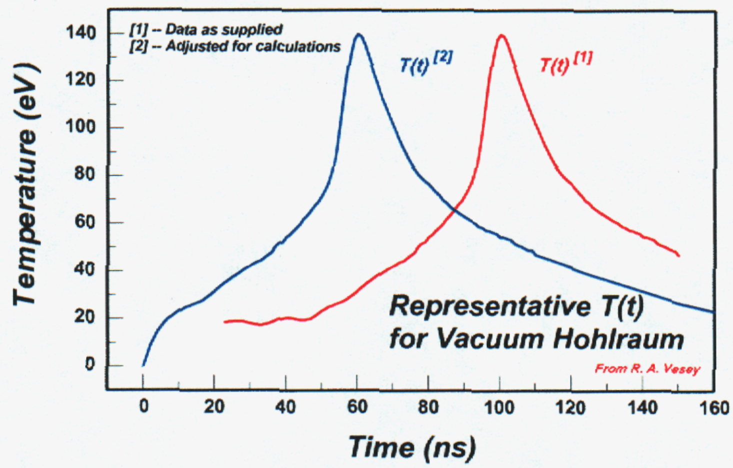
The new hohlraum temperature history was adjusted for the ALEGRA calculations.



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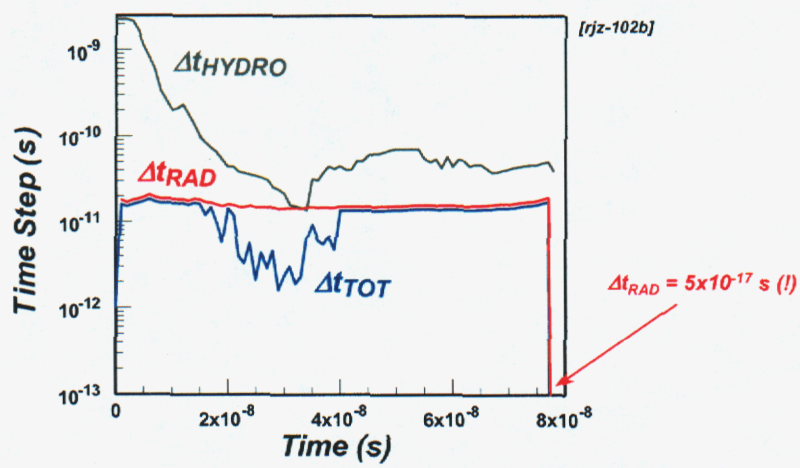
An anomaly in the radiation time step calculation terminated the ALEGRA run at ~80 ns.



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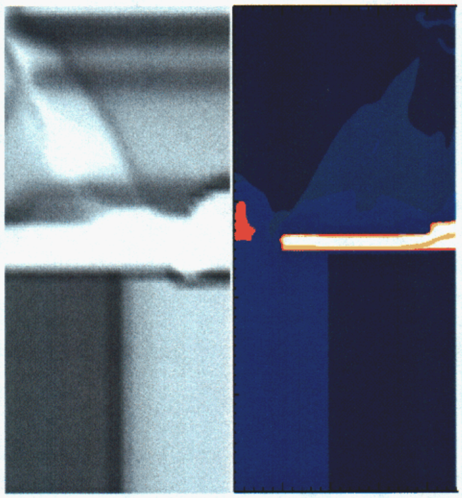
Although the calculation has not been run to completion, we have obtained preliminary results.

Synthetic radiograph from SPECT3D at 78 ns



Density plot from ALEGRA at 78 ns

hν = 6.7 keV [rjz-102b.exo]

[rjz-102b.exo]

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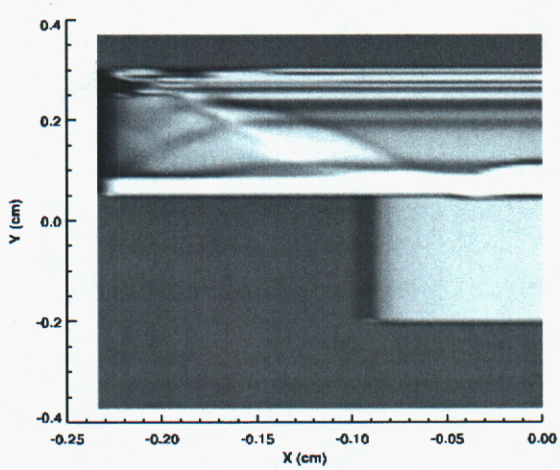
Raw optical density plot from SPECT3D using ALEGRA output . . .



t = 78 ns
hν = 6.7 keV
[rjz-102b.exo]

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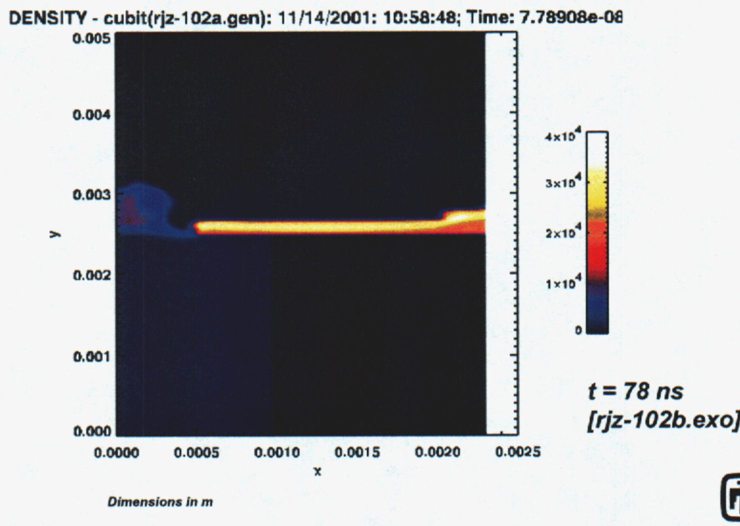
Raw density plot from ALEGRA . . .



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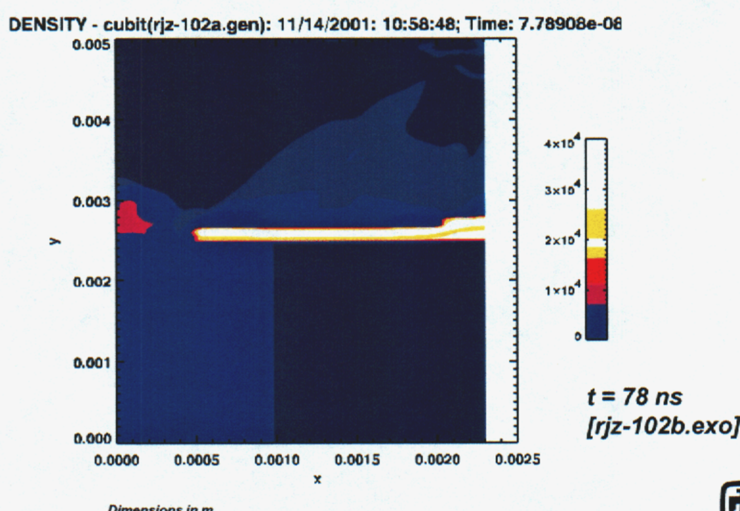
Enhanced density plot from ALEGRA . . .



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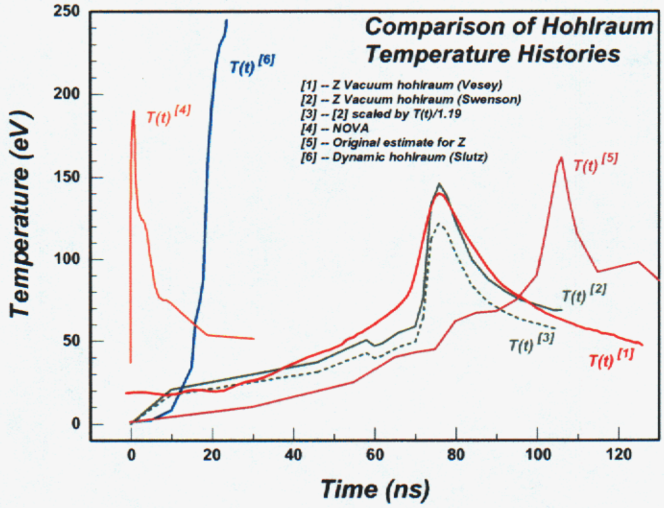
Different radiation environments can be used for these types of RadJet studies.



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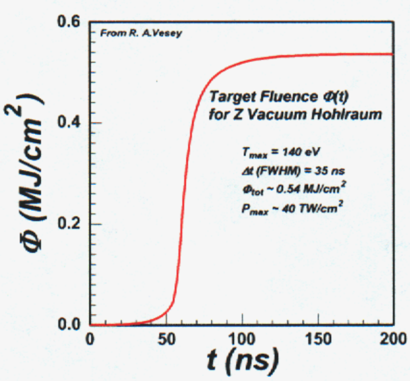
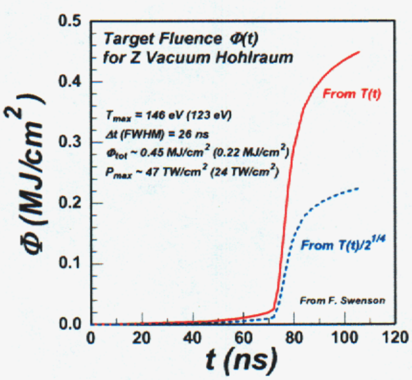
The total fluences on-target can differ significantly, depending on the source.

Vesey:



Swenson:



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We have studied the generation and evolution of radiation-driven jets on both NOVA and Z.

- The NOVA experiments, in conjunction with the other calculations, have provided validation for the ALEGRA modeling and analyses.
- In comparison with the results from NOVA, a 10X physical scale-up of the configuration produces similar phenomenology using the Z-pinch machine.
- Using the Z-Beamlet Backlighter (ZBL) for diagnostic measurements appears to be feasible for the 10X scale-up experiments on Z.
  - At late times and for 10 keV photon energies, optical depths of order unity can be achieved.
- To provide an extra safety margin, we are investigating a 5X physical scale-up for Z.
  - The use of 6.7 keV photon energies (iron) for ZBL will also be possible.
  - Other possibilities include modifying the Z source to obtain different conditions (*e.g.*, higher temperatures via dynamic hohlraum, multiple and/or colliding jets).

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